EXPRESS MAIL MAILING LABEL
No. EV289511312US

Express Mail No. EM494319587US

Patent Application
Docket Number ASX-015

Toroidal Low-Field Reactive Gas Source

COPY

Field of the Invention

This invention relates generally to the field of generating activated gas containing ions, free radicals, atoms and molecules and to apparatus for and methods of processing materials with activated gas.

Background of the Invention

Plasma discharges can be used to excite gases to produce activated gases containing ions, free radicals, atoms and molecules. Activated gases are used for numerous industrial and scientific applications including processing solid materials such as semiconductor wafers, powders, and other gases. The parameters of the plasma and the conditions of the exposure of the plasma to the material being processed vary widely depending on the application.

For example, some applications require the use of ions with low kinetic energy (i.e. a few electron volts) because the material being processed is sensitive to damage. Other applications, such as anisotropic etching or planarized dielectric deposition, require the use of ions with high kinetic energy. Still other applications, such as reactive ion beam etching, require precise control of the ion energy.

Some applications require direct exposure of the material being processed to a high density plasma. One such application is generating ion-activated chemical reactions. Other such applications include etching of and depositing material into high aspect ratio structures. Other applications require shielding the material being processed from the plasma because the material is sensitive to damage caused by ions or because the process has high selectivity requirements.

Plasmas can be generated in various ways including DC discharge, radio frequency (RF) discharge, and microwave discharge. DC discharges are achieved by applying a potential between two electrodes in a gas. RF discharges are achieved either by electrostatically or inductively coupling energy from a power supply into a plasma. Parallel plates are typically used for electrostatically coupling energy into a plasma. Induction coils are typically used for inducing current into the plasma. Microwave discharges are achieved by directly coupling microwave energy through a microwave-passing window into a discharge chamber containing a gas. Microwave discharges are advantageous because they can be used to support a wide range of discharge conditions, including highly ionized electron cyclotron resonant (ECR) plasmas.

RF discharges and DC discharges inherently produce high energy ions and, therefore, are often used to generate plasmas for applications where the material being processed is in direct contact with the plasma. Microwave discharges produce dense, low ion energy plasmas and, therefore, are often used to produce streams of activated gas for "downstream" processing. Microwave discharges are also useful for applications where it is desirable to generate ions at low energy and then accelerate the ions to the process surface with an applied potential.

However, microwave and inductively coupled plasma sources require expensive and complex power delivery systems. These plasma sources require precision RF or microwave power generators and complex matching networks to match the impedance of the generator to the plasma source. In addition, precision instrumentation is usually required to ascertain and control the actual power reaching the plasma.

RF inductively coupled plasmas are particularly useful for generating large area plasmas for such applications as semiconductor wafer processing. However, prior art RF inductively coupled plasmas are not purely inductive because the drive currents are only weakly coupled to the plasma. Consequently, RF inductively coupled plasmas are inefficient and require the use of high voltages on the drive coils. The high voltages produce high electrostatic fields that cause high energy ion bombardment of reactor

surfaces. The ion bombardment deteriorates the reactor and can contaminate the process chamber and the material being processed. The ion bombardment can also cause damage to the material being processed.

Faraday shields have been used in inductively coupled plasma sources to contain the high electrostatic fields. However, because of the relatively weak coupling of the drive coil currents to the plasma, large eddy currents form in the shields resulting in substantial power dissipation. The cost, complexity, and reduced power efficiency make the use of Faraday shields unattractive.

Summary of the Invention

It is therefore a principle object of this invention to provide a source of activated gas that uses a high efficiency RF power coupling device which couples power into a plasma without the use of conventional RF or microwave generators and impedance matching systems.

It is another principle object of this invention to provide a source of activated gas for materials processing where there is no significant energetic ion bombardment within the process reactor and where long-term operation can be sustained using chemically reactive gases without damage to the source and without production of contaminant materials.

It is another principle object of this invention to provide a source of activated gas in which either a metal, a dielectric, or a coated metal (e.g. anodized) can be used to form the source chamber.

A principal discovery of the present invention is that switching semiconductor devices can be used to efficiently drive the primary winding of a power transformer that couples electromagnetic energy to a plasma so as to form a secondary circuit of the transformer. It is another principal discovery of this invention that an inductively-driven toroidal plasma source can be constructed with a metallic plasma chamber.

Accordingly, the present invention features an apparatus for dissociating gases that includes a plasma chamber. The plasma chamber may be formed from a metallic material such as aluminum or may be formed from a dielectric material such as quartz. The metallic material may be a refractory metal. The apparatus may include a process chamber that is coupled to the plasma chamber and positioned to receive reactive gas generated by a plasma in the plasma chamber.

The apparatus also includes a transformer having a magnetic core surrounding a portion of the plasma chamber and having a primary winding. One or more switching semiconductor devices are directly coupled to a voltage supply and have an output coupled to the primary winding of the transformer. The output of the one or more switching semiconductor devices may be directly coupled to the primary winding of the transformer. The one or more switching semiconductor devices may be switching transistors. The voltage supply may be a line voltage supply or a bus voltage supply.

The apparatus may include a free charge generator which assists the ignition of a plasma in the chamber. In a preferred embodiment, an electrode is positioned in the chamber to generate the free charges. In another preferred embodiment, an electrode is capacitively coupled to the chamber to generate the free charges. In another preferred embodiment, an ultraviolet light source is optically coupled to the chamber to generate the free charges.

The apparatus may include a circuit for measuring electrical parameters of the primary winding and of the plasma. The circuit measures parameters such as the current driving the primary winding, the voltage across the primary winding, the bus supply voltage, the average power in the primary winding, and the peak power in the primary winding. A power control circuit may be coupled to the circuit for measuring electrical parameters of the primary winding and the plasma. The power control circuit regulates the current flowing through the primary windings based upon a measurement of the electrical properties of the primary winding and of the plasma and from a predetermined set point representing a desired operating condition.

The present invention also features a method for dissociating gases. The method includes providing a chamber for containing a gas at a pressure. The pressure may be substantially between 1 mtorr and 100 torr. The gas may comprise a noble gas, a reactive gas or a mixture of at least one noble gas and at least one reactive gas. The method also includes providing a transformer having a magnetic core surrounding a portion of the chamber and having a primary winding.

In addition, the method includes directly coupling one or more switching semiconductor devices to a voltage supply, which may be a line voltage supply or a bus voltage supply. The one or more switching semiconductor devices are also coupled to the primary winding of the transformer so that they generate a current that drives the primary winding. The one or more switching semiconductor devices may be directly coupled to the primary winding of the transformer.

The method also includes inducing a potential inside the plasma chamber with the current in the primary winding of the transformer. The magnitude of the induced potential depends on the magnetic field produced by the core and the frequency at which the switching semiconductor devices operate according to Faraday's law of induction. The potential forms a plasma which completes a secondary circuit of the transformer. The electric field of the plasma may be substantially between 1-100 V/cm. The method may include providing an initial ionization event in the chamber. The initial ionization event may be the application of a voltage pulse to the primary winding or to an electrode positioned in the plasma chamber. The initial ionization event may also be exposing the chamber to ultraviolet radiation.

The method may include the step of measuring electrical parameters of the primary winding and of the plasma including one or more of the current driving the primary winding, the voltage across the primary winding, the bus voltage, the average power in the primary winding, and the peak power in the primary winding. In addition, the method may include the step of determining an output of the one or more switching semiconductor devices from the measurement of the electrical parameters of the primary

winding, the plasma, and from a predetermined set point representing a desired operating condition.

The present invention also includes a method for cleaning a process chamber. The method includes providing a plasma chamber that is coupled to the process chamber. The plasma chamber contains a reactive gas at a pressure. A transformer is provided having a magnetic core surrounding a portion of the plasma chamber and having a primary winding. One or more switching semiconductor devices is directly coupled to a voltage supply for generating a current that drives the primary winding of the transformer.

In addition, the method includes inducing a potential inside the plasma chamber with the current in the primary winding. The magnitude of the induced potential depends on the magnetic field produced by the core and the frequency at which the switching semiconductor devices operate according to Faraday's law of induction. The potential forms a plasma which completes a secondary circuit of the transformer. The method also includes directing chemically active species such as atoms, molecules and radicals generated in the plasma from the plasma chamber into the process chamber thereby cleaning the process chamber.

The present invention also includes a method for generating reactive gases. The method includes providing a plasma chamber that is coupled to the process chamber. The plasma chamber contains a reactive gas at a pressure. A transformer is provided having a magnetic core surrounding a portion of the plasma chamber and having a primary winding. One or more switching semiconductor devices is directly coupled to a voltage supply for generating a current that drives the primary winding of the transformer.

In addition, the method includes inducing a potential inside the plasma chamber with the current in the primary winding. The magnitude of the induced potential depends on the magnetic field produced by the core and the frequency at which the switching semiconductor devices operate according to Faraday's law of induction. The potential

forms a plasma which completes a secondary circuit of the transformer. The method also includes generating reactive gas in the plasma.

The present invention also features an apparatus for generating ions. The apparatus includes a plasma chamber that may be formed from a metallic material such as a refractory metal. An orifice is positioned in the chamber for directing ions generated by the plasma. A process chamber may be coupled to the orifice in the plasma chamber and adapted to receive ions generated by the plasma. Accelerating electrodes may be positioned in the process chamber for accelerating ions generated by the plasma.

The apparatus includes a transformer having a magnetic core surrounding a portion of the plasma chamber and having a primary winding. One or more switching semiconductor devices are directly coupled to a voltage supply, which may be a line voltage supply or a bus voltage supply, and have an output coupled to the primary winding of the transformer. In operation, the one or more switching semiconductor devices drives current in the primary winding of the transformer. The current induces a potential inside the chamber that forms a plasma which completes a secondary circuit of the transformer. Ions are extracted from the plasma through the orifice. The ions may be accelerated by the accelerating electrodes.

The present invention also features another apparatus for dissociating gases. The apparatus includes a plasma chamber that comprises an electrically conductive material such as aluminum and at least one dielectric region that prevents induced current flow in the chamber. The plasma chamber may include a plurality of dielectric regions separating at least two regions of the plasma chamber. The dielectric region may comprise a dielectric coating on at least one mating surface of the chamber. The plasma chamber may also include cooling channels for passing a fluid that controls the temperature of the chamber.

In addition, the apparatus includes a transformer having a magnetic core surrounding a portion of the plasma chamber and having a primary winding. The apparatus also includes a power supply that has an output electrically connected to the

primary winding of the transformer. The power supply drives current in the primary winding that induces a potential inside the chamber that forms a plasma which completes a secondary circuit of the transformer. The power supply may comprise one or more switching semiconductor devices that are directly coupled to a voltage supply and that have an output coupled to the primary winding of the transformer. The voltage supply may comprise a line voltage supply or a bus voltage supply.

The apparatus may include a means for generating free charges that assists the ignition of a plasma in the chamber. In a preferred embodiment, an electrode is positioned in the chamber to generate the free charges. In another preferred embodiment, an electrode is capacitively coupled to the chamber to generate the free charges. In another preferred embodiment, an ultraviolet light source is optically coupled to the chamber to generate the free charges.

Brief Description of the Drawings

This invention is described with particularity in the appended claims. The above and further advantages of this invention may be better understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic representation of a toroidal low-field plasma source for producing activated gases that embodies the invention.

FIG. 2 illustrates a plot of etch rate of thermal silicon dioxide as a function of NF3 feed gas flow rate, using the toroidal low-field plasma source that embodies the invention.

FIG. 3 is a schematic representation of a metallic plasma chamber that may be used with the toroidal low-field plasma source described in connection with FIG. 1.

FIG. 4 is a schematic representation of a dielectric spacer suitable for the dielectric regions illustrated in FIG. 3 that prevent induced current flow from forming in the plasma chamber.

FIG. 5 is a schematic representation of a toroidal low-field ion beam source that embodies the invention and that is configured for high intensity ion beam processing.

FIG. 6 is a schematic block diagram of a solid state switching power supply that includes the one or more switching semiconductor devices of FIG. 1.

Detailed Description

FIG. 1 is a schematic representation of a toroidal low-field plasma source 10 for producing activated gases that embodies the invention. The source 10 includes a power transformer 12 that couples electromagnetic energy into a plasma 14. The power transformer 12 includes a high permeability magnetic core 16, a primary coil 18, and a plasma chamber 20 which allows the plasma 14 to form a secondary circuit of the transformer 12. The power transformer 12 can include additional magnetic cores and conductor primary coils (not shown) that form additional secondary circuits.

The plasma chamber 20 may be formed from a metallic material such as aluminum or a refractory metal, or may be formed from a dielectric material such as quartz. One or more sides of the plasma chamber 20 may be exposed to a process chamber 22 to allow charged particles generated by the plasma 14 to be in direct contact with a material to be processed (not shown). A sample holder 23 may be positioned in the process chamber 22 to support the material to be processed. The material to be processed may be biased relative to the potential of the plasma.

A voltage supply 24, which may be a line voltage supply or a bus voltage supply, is directly coupled to a circuit 26 containing one or more switching semiconductor devices. The one or more switching semiconductor devices may be switching transistors. The circuit may be a solid state switching power supply. An output 28 of the circuit 26 may be directly coupled to the primary winding 18 of the transformer 12.

The toroidal low field plasma source 10 may include a means for generating free charges that provides an initial ionization event that ignites a plasma in the plasma chamber 20. The initial ionization event may be a short, high voltage pulse that is

applied to the plasma chamber. The pulse may have a voltage of approximately 500-10,000 volts and may be approximately 0.1 to 10 microseconds long. A noble gas such as argon may be inserted into the plasma chamber 20 to reduce the voltage required to ignite a plasma. Ultraviolet radiation may also be used to generate the free charges in the plasma chamber 20 that provide the initial ionization event that ignites the plasma in the plasma chamber 20.

In a preferred embodiment, the short, high voltage electric pulse is applied directly to the primary coil 18 to provide the initial ionization event. In another preferred embodiment, the short, high voltage electric pulse is applied to an electrode 30 positioned in the plasma chamber 20. In another preferred embodiment, the short, high voltage electric pulse is applied to an electrode 32 that is capacitively coupled to the plasma chamber 20 by a dielectric. In another preferred embodiment, the plasma chamber 20 is exposed to ultraviolet radiation emitting from an ultraviolet light source 34 that is optically coupled to the plasma chamber 20. The ultraviolet radiation causes the initial ionization event that ignites the plasma.

The toroidal low field plasma source 10 may also include a circuit 36 for measuring electrical parameters of the primary winding 18. Electrical parameters of the primary winding 18 include the current driving the primary winding 18, the voltage across the primary winding 18, the bus or line voltage supply generated by the voltage supply 24, the average power in the primary winding 18, and the peak power in the primary winding 18.

In addition, the plasma source 10 may include a means for measuring relevant electrical parameters of the plasma 14. Relevant electrical parameters of the plasma 14 include the plasma current and power. For example, the source 10 may include a current probe 38 positioned around the plasma chamber 20 to measure the plasma current flowing in secondary of the transformer 12. The plasma source 10 may also include an optical detector 40 for measuring the optical emission from the plasma 14. In addition, the plasma source 10 may include a power control circuit 42 that accepts data from one or

more of the current probe 38, the power detector 40, and the circuit 26 and then adjusts the power in the plasma by adjusting the current in the primary winding 18.

In operation, a gas is bled into the plasma chamber 20 until a pressure substantially between 1 mtorr and 100 torr is reached. The gas may comprise a noble gas, a reactive gas or a mixture of at least one noble gas and at least one reactive gas. The circuit 26 containing switching semiconductor devices supplies a current to the primary winding 18 that induces a potential inside the plasma chamber. The magnitude of the induced potential depends on the magnetic field produced by the core and the frequency at which the switching semiconductor devices operate according to Faraday's law of induction. An ionization event that forms the plasma may be initiated in the chamber. The ionization event may be the application of a voltage pulse to the primary winding or to the electrode 30 in the chamber 20. Alternatively, the ionization event may be exposing the chamber to ultraviolet radiation.

Once the gas is ionized, a plasma is formed which completes a secondary circuit of the transformer. The electric field of the plasma may be substantially between 1-100 V/cm. If only noble gases are present in the plasma chamber 20, the electric fields in the plasma 14 may be as low as 1 volt/cm. If, however, electronegative gases are present in the chamber, the electric fields in the plasma 14 are considerably higher. Operating the plasma source 10 with low electric fields in the plasma chamber 14 is desirable because a low potential difference between the plasma and the chamber will substantially reduce erosion of the chamber by energetic ions and the resulting contamination to the material being processed.

The power delivered to the plasma can be accurately controlled by a feedback loop 44 that comprises the power control circuit 42, the circuit 36 for measuring electrical parameters of the primary winding 18 and the circuit 26 containing one or more switching semiconductor devices. In addition, the feedback loop 44 may include the current probe 38 and optical detector 40.

In a preferred embodiment, the power control circuit 42 measures the power in the plasma using the circuit 36 for measuring electrical parameters of the primary winding 18. The power control circuit 42 then compares the measurement to a predetermined setpoint representing a desired operating condition and adjusts one or more parameters of the circuit 26 to control the power delivered to the plasma. The one or more parameters of circuit 26 include pulse amplitude, frequency, pulse width, and relative phase of the drive pulses to the one or more switching semiconductor devices.

In another preferred embodiment, the power control circuit 42 measures the power in the plasma using the current probe 38 or the optical detector 40. The power control circuit 42 then compares the measurement to a predetermined setpoint representing a desired operating condition and adjusts one or more parameters of the circuit 26 to control the power delivered to the plasma.

The plasma source 10 is advantageous because its conversion efficiency of line power into power absorbed by the plasma is very high compared with prior art plasma sources. This is because the circuit 26 containing one or more switching semiconductor devices that supplies the current to the primary winding 18 is highly efficient. The conversion efficiency may be substantially greater than 90%. The plasma source 10 is also advantageous because it does not require the use of conventional impedance matching networks or conventional RF power generators. This greatly reduces the cost and increases the reliability of the plasma source.

In addition, the plasma source 10 is advantageous because it operates with low electric fields in the plasma chamber 20. Low electric fields are desirable because a low potential difference between the plasma and the chamber will substantially reduce energetic ion bombardment within the plasma chamber 20. Reducing energetic ion bombardment in the plasma chamber 20 is desirable because it minimizes the production of contaminating materials within the plasma chamber 20, especially when chemically reactive gases are used. For example, when fluorine based gases such as NF3 and CF4/02 are used in the plasma source 10 of the present invention, including a plasma

chamber formed from a fluorine resistant material, no or minimal erosion of the chamber was observed after extended exposure to the low ion temperature fluorine plasma.

The plasma source 10 is useful for processing numerous materials such as solid surfaces, powders, and gases. The plasma source 10 is particularly useful for cleaning process chambers in semiconductor processing equipment such as thin film deposition and etching systems. The plasma source 10 is also particularly useful for providing an ion source for ion implantation and ion milling systems.

In addition, the plasma source 10 is useful for providing a source for etching systems used for etching numerous materials used to fabricate semiconductor devices such as silicon, silicon dioxide, silicon nitride, aluminum, molybdenum, tungsten and organic materials such as photoresists, polyimades and other polymeric materials. The plasma source 10 is also useful for providing a source for plasma enhanced deposition of materials of numerous thin films such as diamond films, silicon dioxide, silicon nitride, and aluminum nitride.

The plasma source is also useful for generating reactive gases such as atomic fluorine, atomic chlorine and atomic oxygen. Such reactive gases are useful for reducing, converting, stabilizing or passivating various oxides such as silicon dioxide, tin oxide, zinc oxide and indium-tin oxide. Applications include fluxless soldering, removal of silicon dioxide from silicon surface and passivation of silicon surface prior to wafer processing.

Other applications of the plasma source 10 include modification of surface properties of polymers, metals, ceramics and papers. The plasma source 10 may also be used for abatement of environmentally hazardous gases including fluorine containing compounds such as CF4, NF3, C2F6, CHF3, SF6, and organic compounds such as dioxins and furans and other volatile organic compounds. In addition, the plasma source 10 may be used to generate high fluxes of atomic oxygen, atomic chlorine, or atomic fluorine for sterilization. The plasma source 10 may also be used in an atmospheric pressure torch.

FIG. 2 illustrates a plot of etch rate of thermal silicon dioxide as a function of NF3 feed gas flow rates using the toroidal low-field plasma source that embodies the invention. The toroidal low-field plasma source 10 was configured as a downstream atomic fluorine source. The power was approximately 3.5 kW.

FIG. 3 is a schematic representation of a metallic plasma chamber 100 that may be used with the toroidal low-field plasma source described in connection with FIG. 1. The plasma chamber 100 is formed from a metal such as aluminum, copper, nickel and steel. The plasma chamber 100 may also be formed from a coated metal such as anodized aluminum or nickel plated aluminum. The plasma chamber 100 includes imbedded cooling channels 102 for passing a fluid that controls the temperature of the plasma chamber 100.

As shown, a first 104 and a second high permeability magnetic core 106 surround the plasma chamber 100. The magnetic cores 104, 106 are part of the transformer 12 of FIG. 1. As described in connection with FIG. 1, each of the first 104 and the second core 106 induce a potential inside the chamber that forms a plasma which completes a secondary circuit of the transformer 12. Only one magnetic core is required to operate the toroidal low-field plasma source.

Applicants have discovered that an inductively-driven toroidal low-field plasma source can be made with a metallic plasma chamber. Prior art inductively coupled plasma sources use plasma chambers formed from dielectric material so as to prevent induced current flow from forming in the plasma chamber itself. The plasma chamber 100 of this invention includes at least one dielectric region that electrically isolates a portion of the plasma chamber 100 so that electrical continuity through the plasma chamber 100 is broken. The electrical isolation prevents induced current flow from forming in the plasma chamber itself.

The plasma chamber 100 includes a first 108 and a second dielectric region 110 that prevents induced current flow from forming in the plasma chamber 100. The dielectric regions 108, 110 electrically isolate the plasma chamber 100 into a first 112 and

a second region 114. Each of the first 112 and the second region 114 is joined with a high vacuum seal to the dielectric regions 108, 110 to form the plasma chamber 100. The high vacuum seal may be comprised of an elastomer seal or may be formed by a permanent seal such as a brazed joint. In order to reduce contamination, the dielectric regions 108, 110 may be protected from the plasma. The dielectric regions 108, 110 may comprise a dielectric spacer separating mating surface 116 of the plasma chamber 100, or may be a dielectric coating on the mating surface 116.

In operation, a feed gas flows into an inlet 118. As described in connection with FIG. 1, each of the first 104 and the second core 106 induce a potential inside the plasma chamber 100 that forms a plasma which completes a secondary circuit of the transformer 12. Note that only one magnetic core is required to operate the toroidal low-field plasma source.

The use of metal or coated metal chambers in toroidal low-field plasma sources is advantageous because some metals are more highly resistant to certain chemicals commonly used in plasma processing, such as fluorine based gases. In addition, metal or coated metal chambers may have much higher thermal conductivity at much higher temperatures than dielectric chambers and, therefore, can generate much higher power plasmas.

FIG. 4 is a schematic representation of a dielectric spacer 150 suitable for the dielectric regions illustrated in FIG. 3 that prevent induced current flow from forming in the plasma chamber. In this embodiment, a high vacuum seal 152 is formed outside the dielectric spacer 150. The dielectric region is protected from the plasma by protruded chamber wall 100.

FIG. 5 is a schematic representation of an ion beam source 200 including an toroidal low-field plasma generator that embodies the invention. The ion beam source 200 may be used for numerous ion beam processing applications including ion milling and ion implantation. The ion beam source 200 includes toroidal low field plasma source 202 comprising the metallic plasma chamber 100 described in connection with FIG. 3.

The plasma chamber 100 includes a slit 204 for extracting ions generated by the plasma out of the chamber 100. Accelerating electrodes 206 accelerate the ions passing out of the chamber 100 with a predetermined electric field thereby forming an ion beam where the ions have a predetermined energy.

A mass-separating magnet 208 may be positioned in the path of the accelerated ions to select a desired ion species. A second set of accelerating electrodes may be used to accelerate the desired ion species to a predetermined high energy. An ion lens may be used to focus the high energy ion beam. A vertical 212 and a horizontal axis scanner 214 may be used to scan the ion beam across a sample 216. A deflector 218 may be used to separate the ion beam from any neutral particles so that the ion beam impacts the sample 216 and the neutral particles impact a neutral trap 220.

FIG. 6 is a schematic block diagram of a solid state switching power supply 250 that includes the one or more switching semiconductor devices of FIG. 1. Applicants have discovered that switching semiconductor devices can be used to drive the primary winding of a power transformer that couples electromagnetic energy to a plasma so as to form a secondary circuit of the transformer.

The use of a switching power supply in toroidal low-field plasma source is advantageous because switching power supplies are much less expensive and are physically much smaller in volume and lighter in weight than the prior art RF and microwave power supplies used to power plasma sources. This is because switching power supplies do not require a line isolation circuit or an impedance matching network.

The present invention can use any switching power supply configuration to drive current in the primary winding 18 (FIG. 1). For example, the switching power supply 250 may include a filter 252 and a rectifier circuit 254 that is coupled to a line voltage supply 256. An output 258 of the filter 252 and the rectifier circuit 254 produces a DC voltage which is typically several hundred volts. The output 258 is coupled to a current mode control circuit 260.

The current mode control circuit 260 is coupled to a first 262, 262a and a second isolation driver 264, 264a. The first 262, 262a and the second isolation driver 264, 264a drives a first 266 and a second pair of switching transistors 268. The switching transistors may be IGBT or FET devices. The output of the first 266 and the second pair of switching transistors 268 may have numerous waveforms including a sinusoidal waveform. The output of the switching transistors is coupled by the primary winding and magnetic core 269 to the toroidal plasma 270 which forms the transformer secondary.

Equivalents

While the invention has been particularly shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.